Fourth Semiannual
Progress Report
August 1987

To: National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, MD 20771

Contract: NAS5-28758

Title: Spectral characteristics and the extent of paleosols of the Palouse formation

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(NASA-CR-181208) SPECTRAL CHARACTERISTICS AND THE EXTENT OF PALEOSOLS OF THE PALOUSE FORMATION Semiannual Progress Report No. 4 (Washington State Univ.) 23 p Avail: NTIS HC A02/MF A01 CSCL 08G G3/46

N87-28155

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Introduction

In the fourth six month period of this contract we have worked on field verification of models presented in our third semiannual report. We report work by objective as stated in our proposal.

Progress by Objective:

I.A. Develop spectral relationships from TM data that will define the spatial distribution of soil areas by levels of (1) organic matter in the surface soil, (2) iron oxide and clay in exposed paleosol B horizons, and (3) lime-silica accumulations in exposed paleosol B horizons.

B. Compare areas determined by the method outlined in A to patterns interpreted from color aerial photographs, and to ground observations on bare-soil fields.

We have tested four models which deal with these objectives, the carbon model which we reported on earlier and three new models for iron and combinations of iron with carbon. These models used TM band ratios of 1/4-5/2-3/1 for organic carbon, 5/3-3/1-4/5 for amorphous iron, 3/4-5/4-5/3 for the ratio of amorphous iron to organic carbon, and 1/4-3/4-5/4 for organic carbon developed in the early part of this study. These combinations of TM bands were selected by statistical correlation with soil chemical data as reported earlier (Frazier et al., 1987).

The TM band combination of 1/4-5/2-3/1 which was statistically correlated with organic carbon did not give a good result in the field. Patterns produced by the model were not understandable when compared to organic matter distribution in the field and the pattern of cluster distribution was not understood either. There was no recognizable soil line to guide our classification procedure and this model was abandoned. The remaining three models were field tested by sampling within patterns produced by the models. Fifty-five soil samples were taken for all clusters. Chemical analyses for each sample included organic carbon (C)(easily oxidizable carbon by the method of Nelson and Sommers, 1975) and amorphous iron (Fe_h) (hydroxylamine method of Ross et al., 1985). The means of organic carbon, amorphous iron, and the ratio of Fe_h/C were computed for the soil samples from each cluster location.

Amorphous iron model

TM band ratios 5/3, 3/1, and 4/5 were tested as a means to map the distribution of amorphous iron at the soil surface. Figure 1 shows a plot of the cluster distribution using TM 4/5 and 5/3 (repeated from our third semiannual report, Frazier et al., 1987). It shows a soil line made up of clusters 3, 4, 5, 8 and 10, and several other clusters which represent soils with partial cover by plants. In order to find the amorphous iron content of each cluster, the soils were sampled according to the classified image superimposed on a digitized topographic map. A colored version of this map is presented in Figure 2.

The results of the amorphous iron analyses are shown in Table 1. The iron content varies along the soil line from a low of 4.5 g/kg to 7.1 g/kg. Duncan's multiple range test says that there are only two different categories in this data, clusters 3 and 4 and clusters 5, 8 and 10 (Steel and Torrie, 1960). We have colored the classified image to show the patterns that we feel can be found in the field (Fig. 2). The color codes, chemical data, and DN values are presented in Table 2. The contour lines allow us to see that the highest levels of amorphous iron bearing soils are exposed along ridge tops and on convex slopes. To color the image to match the statistical output we would only need to combine red and yellow and add the pink areas to blue. This would show the most extreme erosion areas.

The amorphous iron contents of the surface soils sampled within each cluster were correlated with mean DN values for each cluster. The best relationship was with TM 5/3 (Fig. 3). Amorphous iron contents in g/kg can be predicted as 14.66 - 0.0537(TM 5/3 * 100) with R^2 of 0.98.

The reasons for seeing more patterns in the field and image than are shown by statistics are probably related to the interaction of amorphous iron and carbon. Covariance and correlation matrices computed for the soil sample data (Table 3) shows that organic carbon provided 87% of the variance and that there is a strong negative correlation between organic carbon and amorphous iron. These clusters are separated because of both factors; however, it is sure that clusters 3 and 4 represent the paleosols. They represent amorphous iron contents typically found in these paleosols and reported by us earlier (Frazier et al., 1987).

Organic carbon model

The carbon model is the same as that reported by us earlier. The distribution of clusters (Fig. 4) is repeated for clarity. In this case the soil line parallels the Y axis (TM 5/4). Table 4 shows the organic carbon contents found at the soil surface in each of the clusters of the soil line. It ranges from 5 g/kg to 21 g/kg. The statistical analysis again shows that not all clusters are different. In some cases this is probably related to the small sample size. We sampled only those clusters where we were sure of our location.

A color coded map of the organic carbon model is shown in Figure 5. It is colored in one of several possible ways following the results of Duncan's multiple range test. The color code and cluster combinations are shown in Table 5 along with the DN values. The classes are well separated, having about 4 g/kg difference in carbon between them. This result corroborates our earlier findings with this model (Frazier et al., 1986).

Figure 6 shows the linear regression of organic carbon with TM 5/4. The content of organic carbon in g/kg can be predicted by the equation -43.4 + 0.297(TM 5/4 * 100) with an R^2 of 0.98. In our earlier test (Frazier et al., 1986) we computed an equation for organic carbon in percent, -4.08 + 0.026 (TM 5/4 * 100) with an R^2 of 0.99. (This second equation can be made equivalent to the first equation by multiplying the coefficients by a factor of 10.) The differences between these two equations are small. The difference in prediction of organic carbon is about 0.5%. Differences may be caused by the fact that data are taken from two widely separated areas

and from images of two different years. No attempts have been made to correct the image data for these differences.

Fe_h/C ratio model

The ratio of Fe_h/C is being investigated because of reports in the literature which relate a decrease in the ratio to increased effects of erosion (Pazar, 1983), and because we have noticed that the organic carbon model and the amorphous iron model used separately each find a few eroded areas not distinguished by the other. Since amorphous iron and organic carbon are inversely related they have the potential of showing good results if used together.

Earlier work revealed that the best spectral combination for this model was TM 3/4, 5/4, and 5/3 (Frazier et al., 1987). For clarity, Figure 7 is repeated from that report. It shows the cluster distribution for the model. The soil line is parallel to the TM 5/3 axis. Table 6 shows the Fe_h/C ratios found in the field data for those clusters and gives the Duncan multiple range test grouping for the data. Again, it is probable that small sample size keeps the test from showing separations that we think can be made in the field.

By regressing these ratio values on the corresponding DN values of TM 5/3, the ratio of Fe_h/C is found to be a power function of TM 5/3. There is a significant correlation between them (R^2, 0.96). The function is $Fe_h/C = 1.437 * 10^{16} * (TM\ 5/3 * 100)^{-6.516}$ (Fig. 8). This function is useful because it allows maximum separations to be made in the eroded soils, which are at the steep end of the curve. Table 7 shows the color codes, Fe_h/C ratios and DN values for the model as presented in Figure 9. No clusters have been combined, though according to the statistical tests, some could be. It is our impression after having been in the field with this model that the effects of erosion are shown very well.

Comparison of three models

It is useful to compare the results of these three models. Table 8 shows selected data from each model and the amount of area classified by each cluster. The organic carbon and amorphous iron models are virtually identical with respect to the amount of iron found in the clusters. The carbon model has one additional class at the high end and could conceivably have more classes if used on fields with more carbon. The model for Fe_h/C makes a different division of the spectral values at the low carbon end of the soil line. Cluster 22 shows soils that have suffered the severest erosion. There is no hint of any soil horizon which may have contained carbon remaining on them. The soils in clusters 23 and 24 are only slightly better. Approximately 20% of this field suffers from substantial erosion, and on the other end of the scale, about 63% has accumulated sediment or has only slight erosion. The remaining 17% is on sloping land (pink areas shown in Fig. 9) and is highly susceptible to erosion.

These models are being tested further on other sites around the Palouse region. We are attempting to develop a spectral data set that will work

throughout the region, including the carbonate soil zone as well as the iron enrichment zone. Experience thus far shows that each model works best in the area that it was developed in. The Fe_h/C model seems to be a good candidate for further development. The spectral data set based on TM 5/3, 3/4, and 5/4 separates the iron enriched paleosols from the carbonate paleosols <u>most</u> of the time, but not <u>all</u> of the time. It shows eroded areas all of the time and will be used to establish erosion severity data for the Palouse region.

I.C. Define, on the basis of results of A and B to the extent possible, where exposed paleosols exist within fields that are not bare, but have a crop cover, and the distribution of desirable and undesirable soil properties in each field.

Our discussion of this objective is to present ideas being pursued rather than present results. We were able to show in our third semiannual report that paleosols partially covered by green plants could be mapped using principal components analysis (Frazier et al., 1987). However, we would like to have a method which is more definitive of the actual soil signal than principal components are. The positioning of clusters in a distribution plot may hold an answer to this question. Figure 4 shows such a distribution for the organic carbon model and will serve well to illustrate the theory behind this idea. Cluster 1 in Figure 4 represents the point of greenness where soil cover by plants is complete. The soil line is made up of clusters which represent completely bare soils. All of the clusters in between have varying amounts of green cover which increases from the soil line to cluster 1. If green cover were added in equal amounts to each cluster in the soil line, the whole line should move toward the point of greenness while maintaining its parallel orientation to the TM 5/4 axis. The positions of the soil clusters within the line should not change relative to each other because the soil reflectance has not been changed by adding plant cover. Adding plant cover reduces reflectance in TM 3 because of chlorophyll and reduces reflectance in TM 5 because of water in the green leaves. TM 4 reflectance is increased for both ratios causing a reduction of the ratio value in both bands as green cover increases.

After viewing several of these cluster distribution plots and their corresponding pixel maps it has become apparent that we may determine where these partially green or mixed pixel clusters fit the soil line and hence determine what kind of soil they contain by projecting a line from the point of greenness through the center of the cluster in question to the soil line. Thus, cluster 20 should be similar to clusters 26 or 27 and cluster 19 should be similar to clusters 22 or 23. Development of this idea will require field sampling to determine the soil characteristics of some of the mixed pixel clusters, but the ones we have observed to date have been adjacent to clusters with the appropriate characteristics.

To further illustrate, Figure 5 contains several of the mixed pixel clusters which we have color coded green because they are partly covered by plants. In the right-center of the bare soil field are two pixels coded green and forming a column. The lower pixel of the two is a representative of cluster 19 which, when projected to the soil line, should be coded

yellow like clusters 22 and 23 which are adjacent to it. The upper pixel represents cluster 18 which, when projected to the soil line, is predicted to be similar to cluster 26. This is only circumstantial evidence of a relationship, but we have predicted many of these and will gather data to prove or disprove the hypothesis as it applies to green cover.

The effects of plant residue cover has not been investigated and is not yet understood. There is no doubt that some of the clusters in the plots that we have shown are positioned where they are partly because of plant residue. This will be taken up in a later investigation.

References

Frazier, B. E., A. Busacca, Y. Cheng, D. Wherry, J. Hart and S. Gill. 1986. Spectral characteristics and the extent of paleosols of the Palouse formation. Semiannual report, August 1986, NASA, Goddard Space Flight Center, Greenbelt, MD 20771. Contract: NAS5-28758 NASA-CR-179727

Frazier, B. E., A. Busacca, Y. Cheng, D. Wherry, J. Hart and S. Gill. 1987. Spectral characteristics and the extent of paleosols of the Palouse formation. Semiannual report, February 1987, NASA, Goddard Space Flight Center, Greenbelt, MD 20771. Contract: NAS5-28758

Nelson, D. W., and L. E. Sommers. 1975. A rapid and accurate procedure for estimation of organic carbon is soils. Indiana Acad. of Sci. Proc. 84:456-462.

Pazar, S. E. 1983. Spectral characteristics of iron oxide and organic matter in eroded soils. Unpublished M.S. Thesis, Purdue Univ., West Lafayette, IN

Ross, G. J., C. Wang, and P. A. Schuppli. 1985. Hydroxylamine and ammonium oxalate solutions as extractants for Fe and Al from soils. Soil Sci. Soc. AM. J. 49:783-785.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Company, Inc., New York, NY

Table 1. Duncan's multiple range test for amorphous iron values.

Alpha = 0.05	DF = 33		MSE = 0.734	
Number of means	2	3	4	5
Critical range	0.832	0.874	0.903	0.923

Means with the same letter are not significantly different

Clusters	sample size	mean Fe_h (g/kg)	Duncan grouping
3	15	7.1	A
4	15	6.5	A
5	8	5.1	B
8	5	4.5	B
10	9	4.6	B

Table 2. Characteristics of surface soils found within clusters of the amorphous iron model.

Cluster	Percent of scene	Mean DN value TM5/3	TM3/1	TM4/5	Fe_h (g/kg)	Color coded
3	5.70	141.4	72.5	62.6	7.10	Red
4	15.33	153.7	69.6	57.3	6.50	Yellow
5	23.14	166.6	67.1	53.4	5.10	Pink
8 & 10	55.83	187.3	63.1	48.9	4.60	Blue

Table 3. Variability and correlations of soil surface iron oxides and organic carbon

Soil properties	C	Fe_h	Fe_d	Percent of variance
	Variance--Covariance Matrix			
C	14.37			87.25
Fe_h	-2.817	1.119		6.79
Fe_d	-1.006	0.471	0.981	5.96
	Correlation Matrix			
C	1.000			
Fe_h	-0.7027	1.000		
Fe_d	-0.2681	0.4498	1.000	

Table 4. Duncan's multiple range test for organic carbon

Alpha = 0.05 DF = 31 MSE = 5.710

Number of means	2	3	4	5	6	7
Critical range	2.915	3.063	3.165	3.230	3.283	3.325

Means with the same letter are not significantly different

Clusters	sample size	mean C (g/kg)	Duncan grouping	
27	7	21.077		A
26	5	16.012		B
24	4	13.427	C	B
25	3	11.870	C	D
23	6	10.057	E	D
22	12	8.280	E	
21	13	5.039		F

Table 5. Characteristics of surface soil found within clusters of the organic carbon model.

Cluster	Percent of scene	Mean DN value TM1/4	TM3/4	TM5/4	C (g/kg)	Color coded
27	26.37	180.7	112.4	213.6	21.10	Dark red
26	22.60	169.6	110.2	201.8	16.00	Orange
24 & 25	29.23	170.6	113.6	190.5	12.70	Pink
22 & 23	17.62	165.6	113.4	174.9	9.20	Yellow
21	4.18	157.5	114.3	161.9	5.00	White

Table 6. Duncan's multiple range test for Fe_h/C ratio

Alpha = 0.05 DF = 31 MSE = 1148.16

Number of means	2	3	4	5	6
Critical range	36.28	38.13	39.40	40.21	40.87

Means with the same letter are not significantly different

Clusters	sample size	mean Fe/C (* 100)	Duncan grouping	
22	10	187.10		A
23	12	97.35		B
25	6	67.14	C	B
26	6	45.95	C	D
27	5	26.75		D
20	9	23.47		D

Table 7. Characteristics of surface soil found within clusters of the Fe_h/c model.

Cluster	Percent of scene	Mean DN value TM3/4	TM5/4	TM5/3	Fe_h/C (*100)	Color coded
20	30.27	110.4	212.1	192.1	23.50	Dark red
27	33.20	112.1	198.7	177.3	26.80	Red
26	16.00	113.5	187.7	165.4	46.00	Pink
25	10.03	114.5	178.3	155.8	67.00	Light pink
23	7.57	113.8	169.6	149.1	97.40	Yellow
22	2.93	115.4	159.5	138.4	187.10	White

Table 8. Comparison of three models

Cluster	Fe_h (g/kg)	C (g/kg)	Fe_h/C *100	Percent of scene
Model for Amorphous iron				
3	7.1	4.9		5.7
4	6.5	8.6		15.3
5	5.1	12.3		23.2
8 & 10	4.6	17.2		55.8
Model for organic carbon				
21	7.1	5.0		4.2
22 & 23	6.3	9.2		17.6
24 & 25	5.0	12.7		29.2
26	4.6	16.0		22.6
27	4.5	21.1		26.4
Model for Fe_h/C				
22	7.4	4.0	187.1	2.9
23	6.8	7.0	97.4	7.6
25	6.2	9.3	67.0	10.0
26	5.3	11.5	46.0	16.0
27	4.0	14.9	26.8	33.2
20	4.6	19.6	23.5	30.3

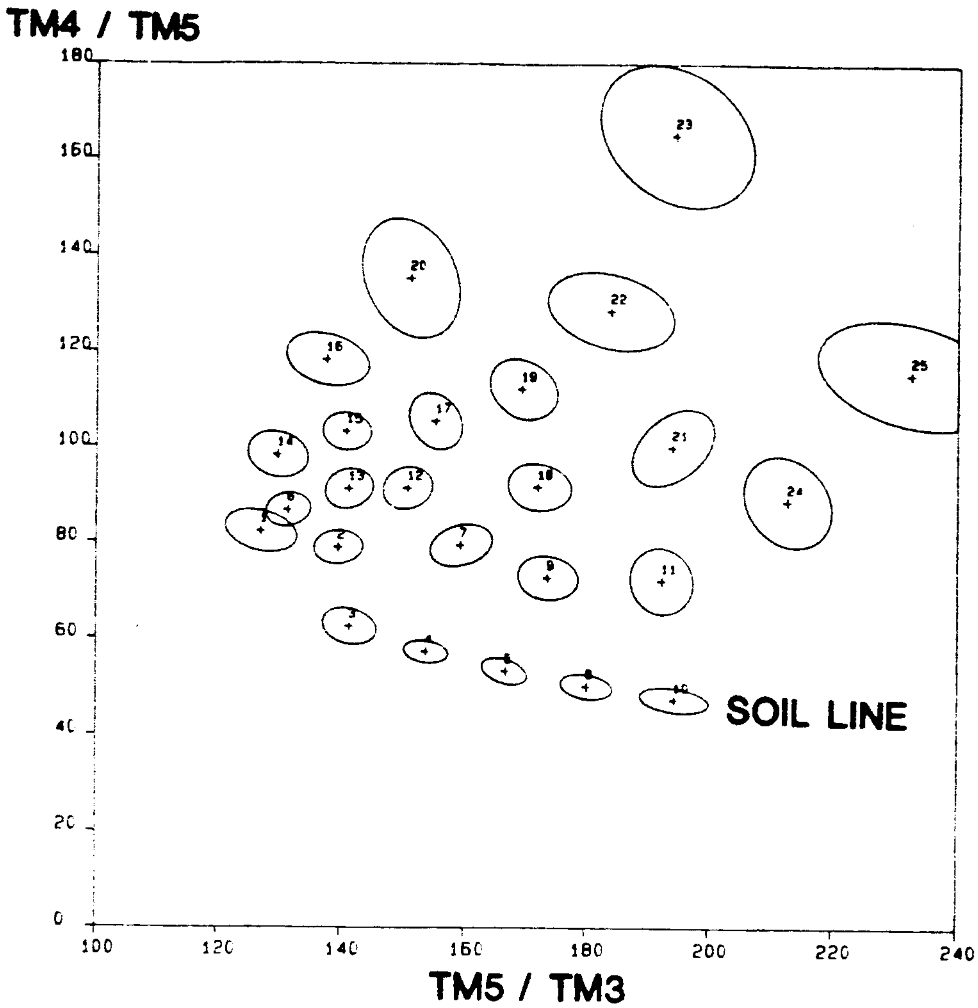

Figure 1. Plot of clusters for the amorphous iron model.

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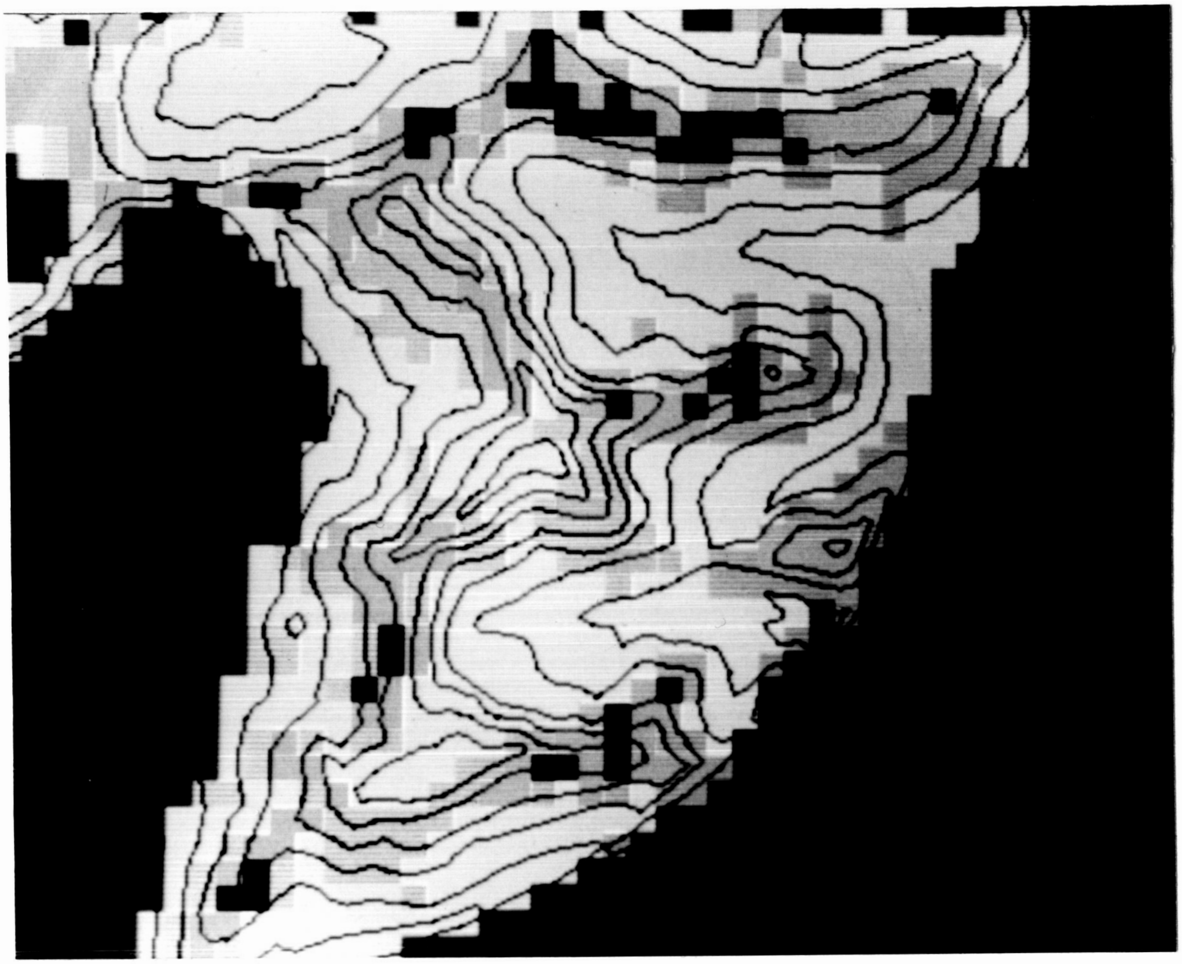

Figure 2. Model of amorphous iron mapped by TM ratios 5/3, 3/1 and 4/5 superimposed on 20 ft contour lines of a bare soil field. The content of iron in g/kg is 7.1, red; 6.5, yellow; 5.5, pink and 4.7, blue. Plant cover is coded green.

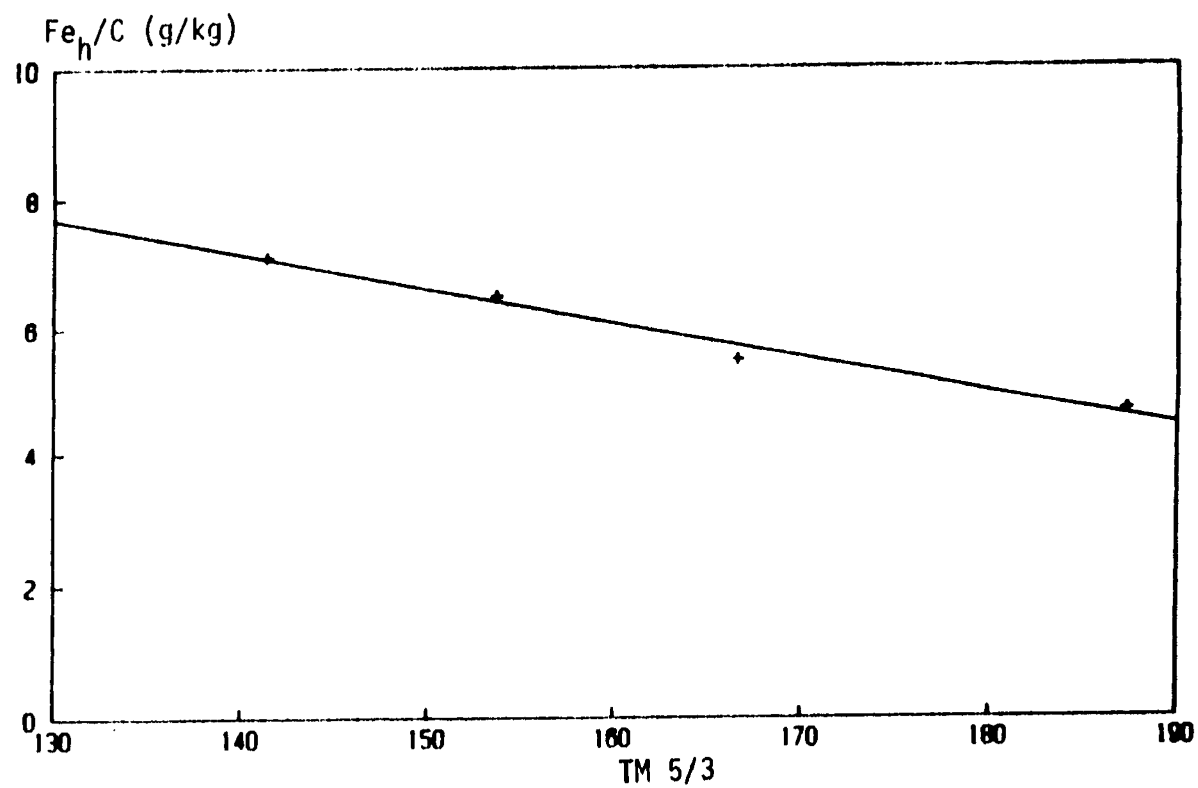

Figure 3. Regression line for amorphous iron with TM ratio 5/3.
14.66 - 0.0537(TM 5/3 * 100) = g/kg amorphous iron.

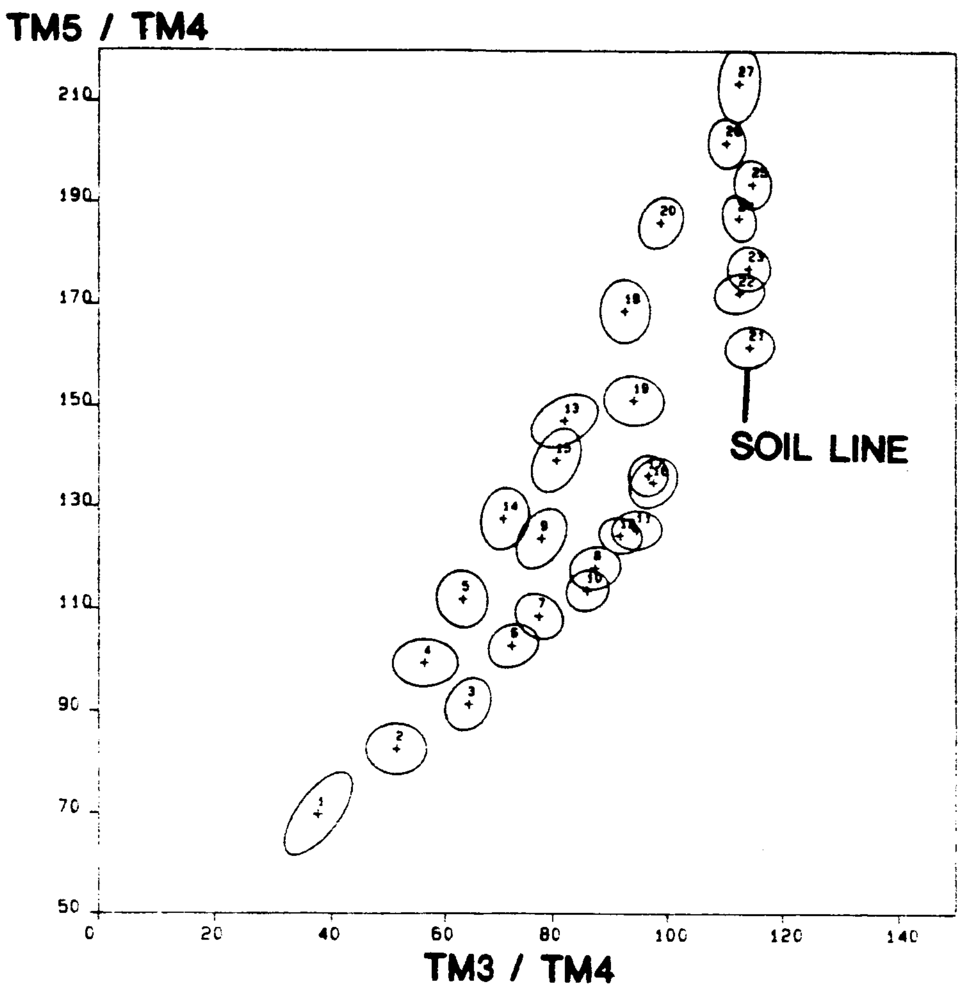

Figure 4. Plot of clusters for the organic carbon model.

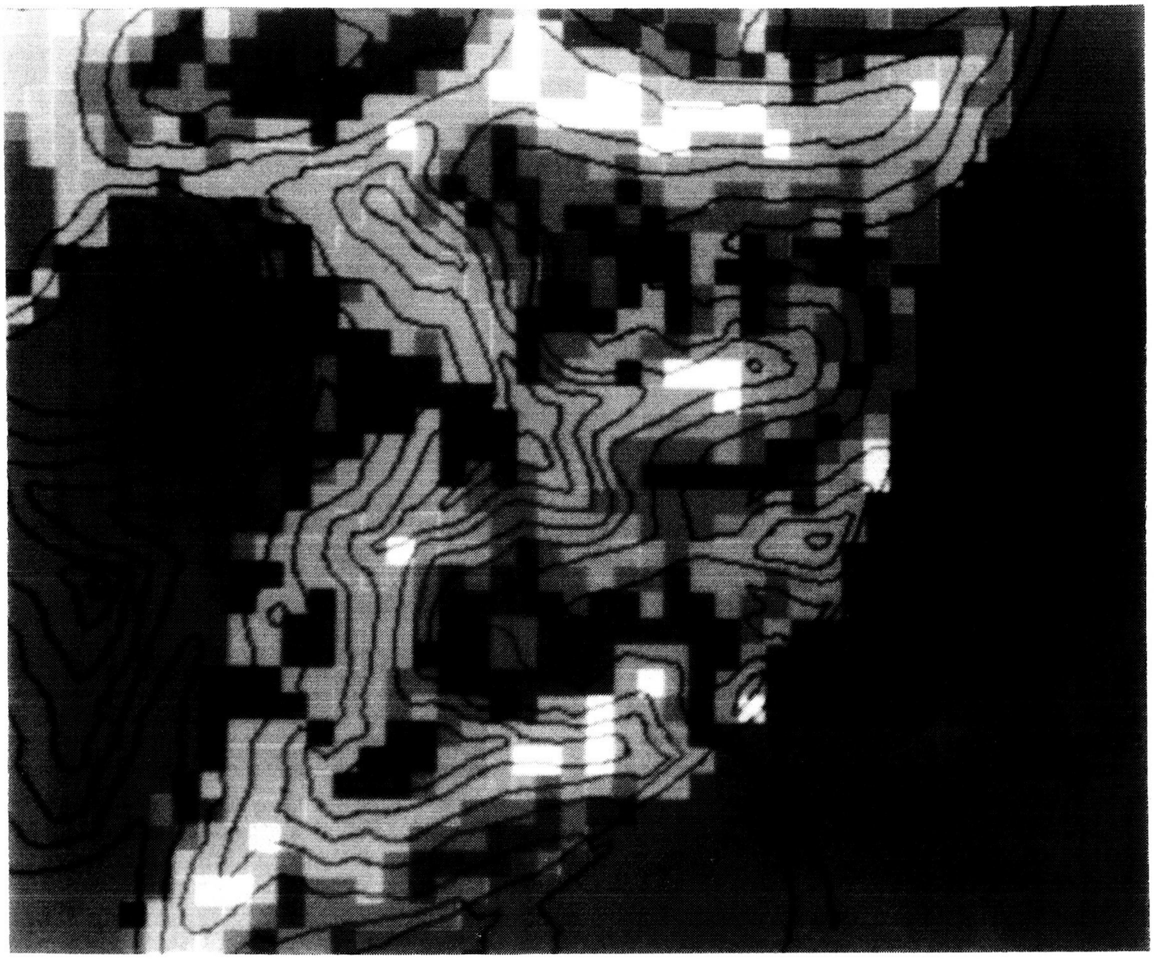

Figure 5. Model of organic carbon mapped by TM ratios 1/4, 3/4 and 5/4 superimposed on 20 ft contour lines of a bare soil field. The content of organic carbon in g/kg is 5.0, white; 9.0, yellow; 12.2, pink; 16.0, orange and 21.0, dark red. Plant cover is coded green.

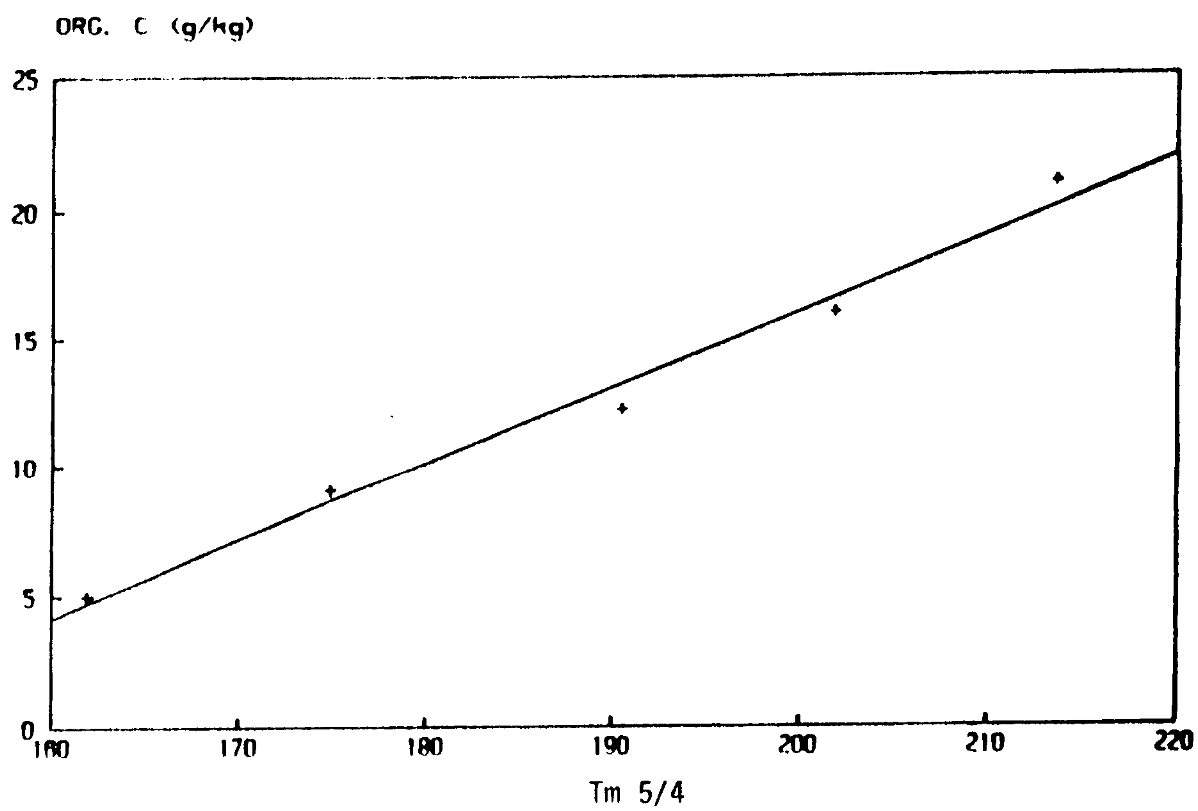

Figure 6. Regression line for organic carbon with TM ratio 5/4.
-43.4 + 0.026(TM 5/4 * 100) = g/kg organic carbon.

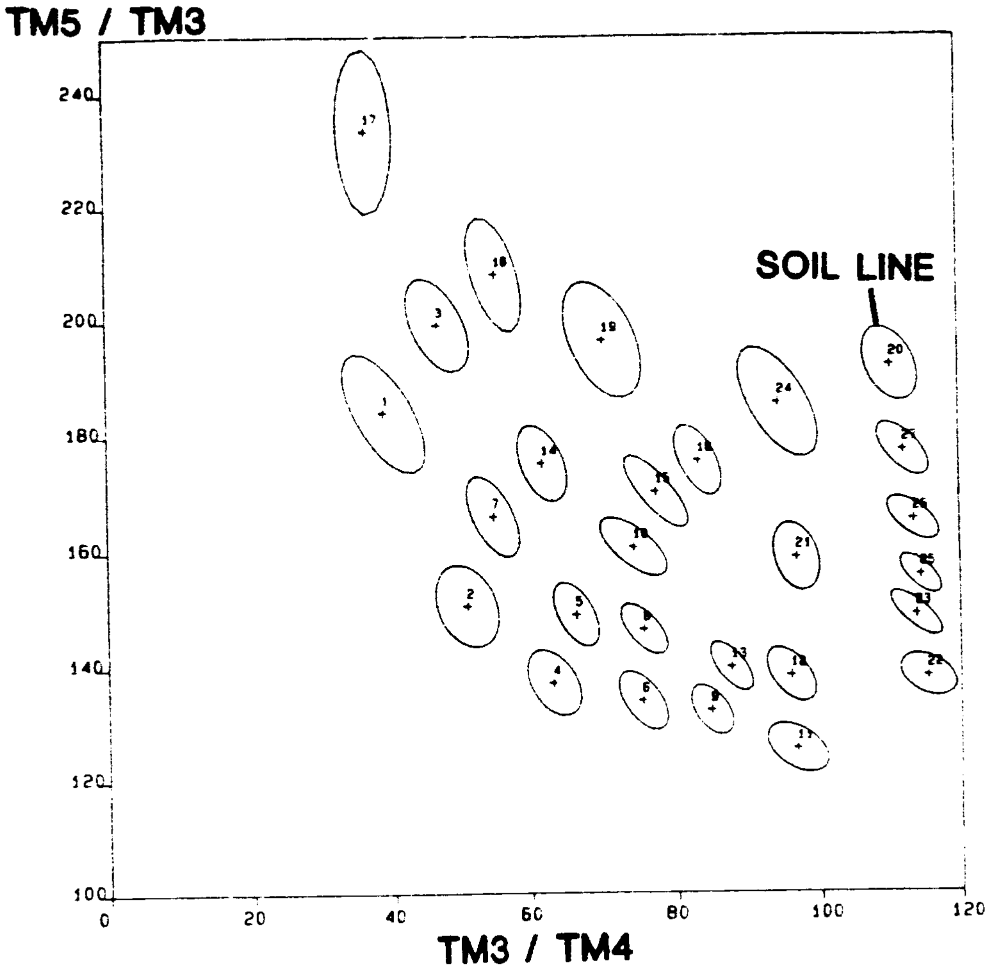

Figure 7. Plot of clusters for the Fe_h/C ratio model.

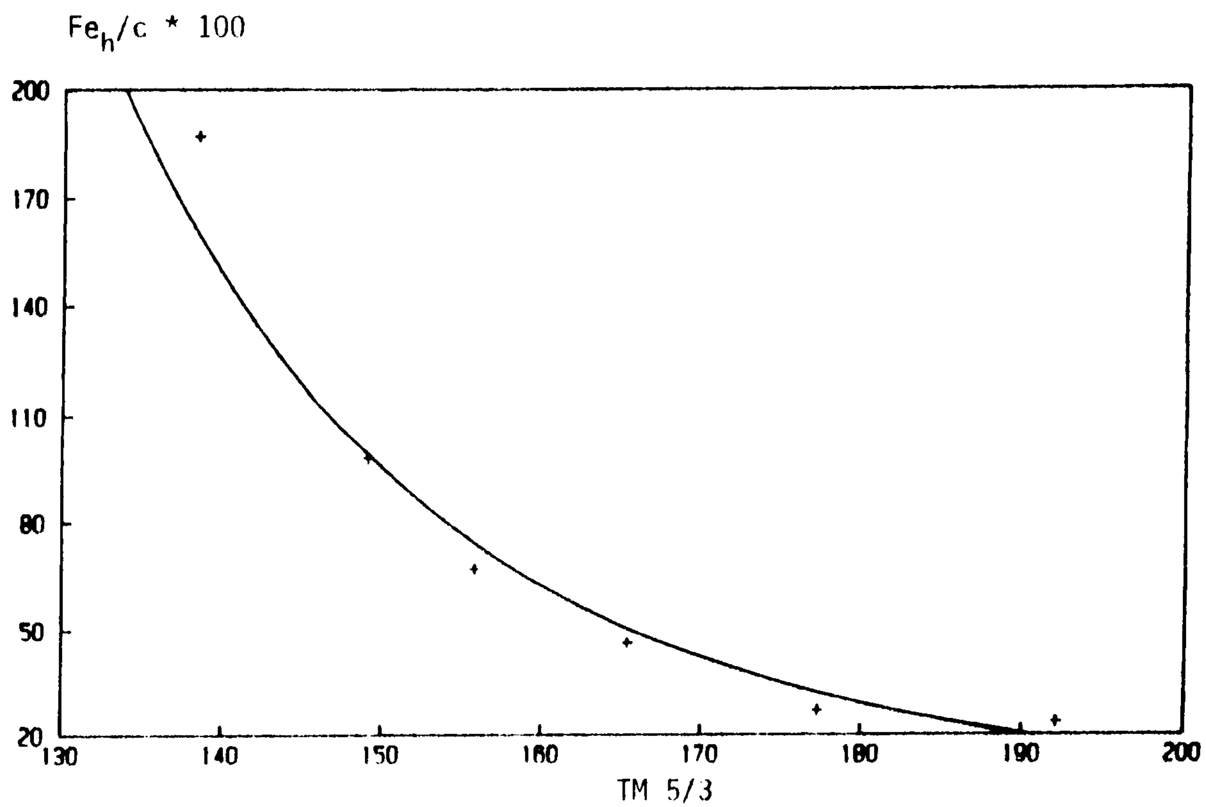

Figure 8. Regression line for the Fe_h/C ratio with TM ratio 5/3. $1.437 * 10^{16}(TM\ 5/3 * 100)^{-6.516} = Fe_h/C$ ratio.

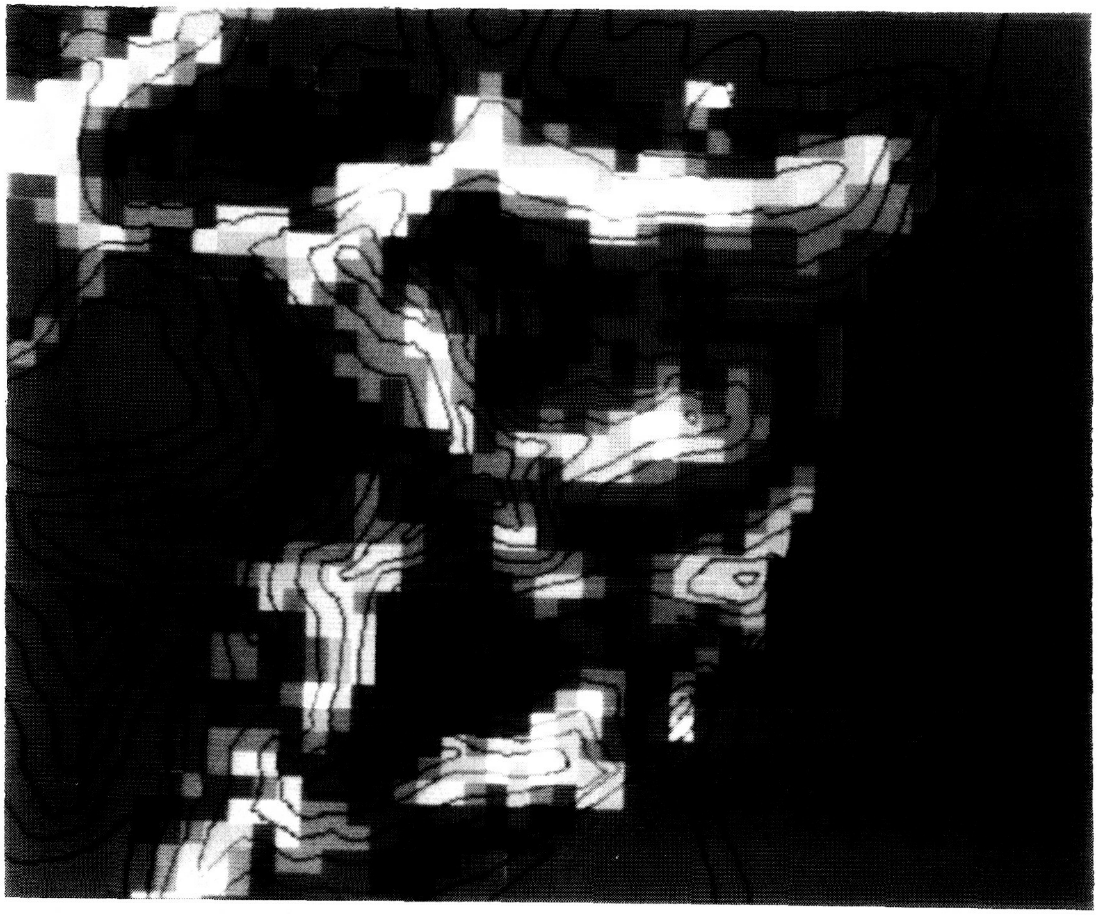

Figure 9. Model of the Fe_h/C ratio mapped by TM ratios 3/4, 5/4 and 5/3 superimposed on 20 ft contour lines of a bare soil field. The ratio * 100 is 187.1, white; 97.4, yellow; 67.0, light pink; 46.0, pink; 26.8, red and 23.5, dark red. Plant cover is coded green.